DRAFT

Review of Scientific Papers and Summary of Key Findings

For the ASC-EPA Technical Workshop on
Estuarine Habitat in the Bay Delta Estuary

AQUATIC SCIENCE CENTER

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Building a Common Library of Scientific Papers

This document summarizes the key findings of selected technical papers on X2, the low salinity zone, and the ecological community of the San Francisco Bay/Sacramento-San Joaquin Delta Estuary (Bay Delta Estuary). The Aquatic Science Center (ASC) prepared the summary to support the technical workshop on estuarine habitat being staged in Sacramento on 27 March 2012 by ASC and EPA. This summary is accompanied by a common library of online scientific papers that workshop participants will be able to access before, during, and after the workshop. ASC analyzed papers in this library to identify common themes, key points of agreement and disagreement (and reasons thereof), and uncertainties.

The common library was built through a relatively informal process. As a starting point, Dr. Bruce Herbold offered an initial list of thirty-six (36) "essential" LSZ/X2 papers produced since 1995. This became known as the "long-list" of papers that provided a useful reference tool to subsequent reviewers of the list. Based on the long-list, Dr. Wim Kimmerer kindly suggested a shorter, more manageable set of papers, and this became known as the "short list." Dr. Kimmerer used the following criteria for selecting a paper for the short list: the paper (1) applies in particular to the low-salinity zone, or to species resident there; and (2) either provides a good overview of the habitat, or provides new looks at particular aspects of that habitat.

Drs. Anke Mueller-Solger and Matt Nobriga graciously reviewed both lists and added their own recommendations. Each scientist arrived at a slightly different list of essential papers, and all agreed that the task was difficult and depended upon the selection criteria for inclusion. Given time constraints, prospective workshop participants were not surveyed about the selection criteria, and ASC and EPA were willing to accept the basic criteria established by Dr. Kimmerer and the collective, best professional judgment of Drs. Herbold, Mueller-Solger, and Nobriga. The final list of 23 papers provided here represents a hybrid of the "desert island" lists that were provided by each expert. The workshop planning team[1] accepted these papers as those most likely to garner the greatest acceptance among workshop participants for their characterization of ecological processes and hydrodynamics pertaining to X2 and the low salinity zone.

[1] Members of the Planning Team for the Estuarine Workshop
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Summary of Key Findings

There are well-accepted statistical relationships between the abundance and survival of fishes and other estuarine species with the location of the low salinity zone (LSZ), as represented by X2 (the 2% bottom salinity position). However, there is a need to more extensively study causal relationships among X2, estuarine habitat quality, and fish populations.

Agreements

The following statements represent general consensus of the science community, as represented in the peer-reviewed literature pertaining to the LSZ or X2:

Habitat

Abundance of Zooplankton and Young Fishes is Centered Near or Slightly Upstream of the LSZ. Bennett et al. (2002), Jassby et al. (1995), Kimmerer et al. (2002), Moyle et al. (1992).

Low Salinity Habitat Distributed Over Shoal Areas Is More Productive and Provides Better Rearing Conditions Than Habitat Confined to Deeper Channels. Overall, the historical sampling record indicates that delta smelt have remained several fold more abundant in northern Suisun Bay and Suisun Marsh channels than in southern Suisun Bay and the Delta. There also appears to be a link between the recruitment success for delta smelt and the availability of shallow-water habitats rather than the amount of freshwater outflow alone (as indexed by X2). Bennett (2005), Bennett et al. (2002), Moyle et al. (1992).

Delta Smelt Habitat Extent. Delta smelt is endemic to the estuary; habitat extends from the tidal freshwater reaches of the Delta seaward to about 19 psu salinity at water temperatures lower than 25°C. Bennett (2005).

Habitat for Northern Anchovy Is Negatively Related to X2.
When the Asian clam *Corbula amurensis* invaded the San Francisco Estuary in 1986, the distribution of northern anchovy (*Engraulis mordax*), the most common fish in the estuary, shifted toward higher salinity, reducing summer abundance in the LSZ by 94%. The response of the anchovy to the arrival of *Corbula* was rapid, manifested in a sharp decline in summer abundance from 1986 to 1987. The resulting shift in the anchovy's spatial distribution in the estuary appears to have been a direct behavioral response to reduced food (i.e., reduction in overall biomass and replacement of preferred zooplankton species by invasives, as indicated by carbon biomass estimates).

Although the abundance of northern anchovy has declined in the low salinity zone, it still dominates the biomass of fish in the more saline reaches of the estuary. The bulk of the anchovy population even before the decline was at high salinity: 95% of the catch before 1987 occurred at salinities greater than 10%.

The disappearance of the northern anchovy from the LSZ may have allowed more successful foraging of remaining species, especially delta smelt and longfin smelt. Northern anchovy is a filter feeder, food density-dependent feeder and thus may be more sensitive to changes in the abundance of their prey than smelt, which are "picking type" of feeders whose feeding success is more of a density independent, or density vague process. Bennett (2005), Kimmerer (2006).

Fish Populations

The Pelagic Organism Decline (POD): Populations of Four Pelagic Fishes Suddenly Declined in the Early 2000s.
Change point models detected step declines in abundances of delta smelt, longfin smelt, striped bass, and threadfin shad in the early 2000s, with a likely common decline in 2002. However, no single factor emerged to explain the POD (see Uncertainties), which is now believed to be the result of multiple effects. Abiotic habitat factors relate directly and indirectly to the declining fish abundances. The conclusion is based on univariate and multivariate analyses of the effects of abiotic habitat variables, in particular X2 and water clarity. Abiotic habitat factors can affect fish by directly increasing or decreasing the extent of their physical habitat and indirectly by impacting their prey or predators.
Bennett (2005), Mac Nally et al. (2010), Thomson et al. (2011).

Delta Smelt and Striped Bass Are More Abundant in More Turbid Waters. Based on generalized additive modeling results, the predicted occurrence of delta smelt and striped bass decreased as Secchi depth increased. Feyrer et al. (2007).

Young Fishes And Zooplankton Can Actively Maintain Position Within the LSZ. Young fishes migrated vertically and maintained position in the LSZ, switching between two strategies depending on freshwater flow and longitudinal position of the LSZ. Zooplankton in the LSZ also migrate vertically with the tides to maintain position, but there are differences among years and between taxa. Bennett et al. (2002), Kimmerer et al. (1998), Kimmerer et al. (2002).

Delta Smelt Is at Risk of Extinction. Limited distribution, short life span, low reproductive capacity, as well as relatively strict abiotic habitat and feeding requirements, are indications that delta smelt is at catastrophic risk in a fluctuating environment. A small percentage (<10%) lives two years and may have an important influence on population dynamics by augmenting spawning success after years of poor recruitment. Bennett (2005).

Flow Response

The Abundance of Several Common Species of Fish Varies Positively With Flow Entering the Estuary, as Indexed by X2.
Based on data collected through 1992, Jassby et al. (1995) presented simple and significant statistical relationships of X2 with annual measures of phytoplankton-derived detritus from river loading; mollusks; mysids (*Neomysis mercedis*); bay shrimp (*Crangon franciscorum*); larval fish survival; and the abundance of longfin smelt (planktivorous), striped bass (piscivorous), and starry flounder (bottom-foraging). The abundance of most of these fish and the shrimp species is elevated in years when mean spring and early summer (April – July) X2 locations are moved seaward (closer to the Golden Gate) by high Delta outflows. The starry flounder abundance index responds to spring X2 in the previous year.

There are also notable exceptions. For example, delta smelt abundance does not correspond to X2. However, Bennett (2005) notes that the abundance of delta smelt is elevated only in years when the low salinity zone is located in Suisun Bay.

Adding 7 to 8 years of post-*Corbula* data (based on availability) to those previously analyzed by Jassby et al. (1995), Kimmerer (2002) found that most of the species that were responsive to flow before *Corbula*'s arrival continue to have statistically demonstrable linkages between abundance or early life stage survival and X2 position. Kimmerer's analyses confirmed that all of the fish and shrimp, except delta smelt, had negative relationships with X2, indicating higher abundance at high flow. Two of them, starry flounder and longfin smelt, had negative relationships with X2 with no significant change in slope before and after 1987 but with lower intercepts after 1987, indicating 4-fold declines in overall abundances after the arrival of *Corbula*.

The bay shrimp *Crangon franciscorum* had a significant relationship with X2 that had not appeared to change since 1988, although both the lowest and highest residuals around the X2 trend line were observed after 1988, indicating a possible transient response either to the change in the food web or to the extended drought from 1985 to 1992. Exceptions to this overall trend of continuity were the response of delta smelt and the mysid shrimp *Neomysis mercedis*, which was previously abundant in the LSZ in summer but declined about 50-fold after 1987. The response of *N.*

mercedis to X2 changed significantly between the two periods, with a negative slope through 1987 (higher at high flow) and a steep positive slope thereafter (higher at low flow). Regressions on delta smelt abundance index data from 1975 – 1999 for two time periods (1975 – 1981 and 1981 – 1999) showed a positive relationship with X2 during the period up to 1981 and a negative but non-significant relationship from 1982 on.

Although X2 is not equivalent to flow, it still reflects the large interannual variability in river flow. Daily, monthly, and seasonal time series regressions demonstrate strong relationships between X2 and Delta outflow. $X2 \sim Q^{1/7}$, based on more than 20 years of data in which flow varies by a factor of approximately 200.
Jassby et al. (1995), Kimmerer (2002), Monismith et al. (2002), Moyle et al. (1992), Nobriga et al. (2008).

Organic Carbon Supply Increases With Flow. The supply rate of organic carbon to the Estuary increases with increasing freshwater flow, mainly because of river-borne inputs. However, much of the organic carbon in wet years is wood and thus less bioactive. Herbold (pers. comm.), Jassby et al. (1995).

Foodweb

Lack of Phytoplankton Blooms in the Upper Estuary. In the two most recent decades, phytoplankton blooms have been rare in the Estuary although nutrient concentrations are high. Blooms in the estuary were common in earlier years, despite higher turbidity. Alpine and Cloern (1992), Dugdale et al. (2007).

***Corbula* Caused a Major Change in the Food Web.** Chlorophyll a and several species of zooplankton (including mysids and some copepods) declined markedly after 1987. Mysids declined by about half and declines in some copepod species were accompanied by increases in other, introduced species. These introduced species are of lower nutritional value (e.g. omega fatty acid content). The now dominant exotic copepod *Limnoithona tetraspina*, is also much smaller than the species it replaced, requiring planktivores to “work harder” to capture equivalent quantities of food. Bennett (2005), Herbold (pers. comm.), Kimmerer (2002), Kimmerer (2006).

Low Salinity Zone

The Salinity Field Embodies Information Not Directly Or Solely Related to the Chemical Properties of Water. The amount of freshwater flow into the Estuary is reflected in the salinity distribution, which in turn may determine the geographic location of estuarine turbidity maxima, entrapment phenomena, or null zones. For example, variation in gravitational circulation at a longer time scale may occur due to movement of the LSZ in response to variation in freshwater flow. Jassby et al. (1995), Peterson et al. (1975).

The LSZ Forms Multiple Turbidity Maxima of Various Origins.
In the varying bathymetry of northern San Francisco Bay, the LSZ can move between shallow and deep water, altering the propensity for gravitational circulation to occur and producing multiple turbidity maxima that are positioned by bottom topography instead of salinity. Gravitational circulation is dependent on depth and more frequently observed in the deeper water column of Carquinez Strait, compared to shallower areas. Bennett et al. (2002), Kimmerer et al. (2002), Schoellhamer (2001).

Habitat Models

Habitat Volume is Highly Correlated With Surface Area.
Kimmerer et al. (2009) simulated habitat volume using the TRIM3D hydrodynamic model and found that slopes of habitat volume vs. X2 were highly correlated with slopes of habitat area vs. X2 ($r^2 = 0.97$). Feyrer et al. (2011), Kimmerer et al. (2009).

Disagreements

Habitat

Examining and Predicting Habitat Use.
Both Kimmerer et al. (2009) and Feyrer et al. (2011) employed General Additive Modeling (GAM) to predict habitat use by estuarine fish. Kimmerer et al. (2009) employed habitat curves based on catch per trawl, because they were usually closer to the underlying fish distributions than those based on frequency of occurrence, which they argue tended to be extremely skewed. Feyrer et al (2011) chose to model frequency of occurrence rather than catch per trawl, as they argue, to minimize the possible influence of outliers and bias associated with long-term abundance declines. Feyrer et al. (2011), Kimmerer et al. (2009).

Flow Response

Fish Responses to X2 Remain a Topic of Debate.
Kimmerer et al. (2009) observed that abundance –springtime X2 relationships correspond with habitat volume-springtime X2 relationships for striped bass, but not for delta smelt, longfin smelt, or in fact, most of the other species examined. These findings imply that increasing quantity of habitat, as defined by salinity, cannot explain the X2 relationships for most of the species and suggests that other mechanisms may be more or

equally important. For example, the abundance index of longfin smelt varied by about two orders of magnitude over the range of X2 values, whereas the observed modest slope of habitat to X2 would allow for only about a twofold variation in abundance index over that X2 range. Kimmerer et al. (2009) conclude that increases in quantity of habitat may contribute to longfin smelt's strong X2 relationship, but that the mechanism chiefly responsible for it remains unknown.

Feyrer et al. and Nobriga et al. (2008) suggest that for delta smelt, the relationship between X2 and abundance is not apparent, because the delta smelt population may be responding to spatial scales smaller than other, more widely distributed species. They also conclude that delta smelt respond to regional salinity patterns through time, and specifically to conditions that occur seasonally in summer and fall. They imply that the springtime X2 (January – June) used by Kimmerer et al. (2009) and Bennett (2005) may not be expected to predict the abundance of delta smelt, due to the fact that these fish, due to other limiting factors, may not arrive in the LSZ until late spring or early summer. Nobriga et al. (2008) found that salinity predicted delta smelt occurrence in summer in three distinct geographic regions (Suisun Bay, Sacramento-San Joaquin River confluence, and San Joaquin Delta) that had similar long-term trends in delta smelt capture probabilities. Through generalized additive modeling, Feyrer et al. (2007) concluded that the combined effects of fall stock abundance and water quality (i.e., salinity and water clarity), predicted recruitment abundance in the following summer, at least during the past two decades, when food availability was severely reduced by *Corbula*.

Bennett (2005), Feyrer et al. (2007), Jassby et al. (1995), Kimmerer (2002), Kimmerer et al. (2009), Nobriga et al. (2008).

Foodweb

Decline in Phytoplankton Biomass.
The downward trend in phytoplankton biomass over the last few decades is combined with "demographic" changes in the phytoplankton community from large diatoms to flagellates, blue-green algae, and smaller species of diatoms. The drivers of the algal trends are still being debated. The large decline in phytoplankton biomass (as measured by chlorophyll a) in Suisun Bay occurred mostly after the introduction of *Corbula* in 1986. The overall decline in phytoplankton biomass came hand in hand with a decline in the proportion of diatoms. Several other drivers are thought to play a role in the observed changes to the algal community. Among them are increased ammonia loadings, water diversions, and a reduction in phosphorus loadings. Earlier observations that phytoplankton has rebounded in the Delta in the late 90s seem to be confounded by more recent data indicating a continuation of the long-term decline.

Baxter et al. (2010), Bennett and Moyle (1996), Brown (2009), Dugdale et al. (2007), Jassby (2008), Jassby et al. (2002), Kimmerer (2002), Kimmerer (2005), Van Nieuwenhuyse (2007), Winder & Jassby (2010).

Decline in Productivity.
Since the mid-1970s, the upper Estuary had experienced declines in phytoplankton biomass, zooplankton abundance, and fish populations. Whether or not these declines are driven by declines in primary productivity and consecutive trophic changes remains a topic of debate. For example, based on the findings by Dugdale et al. (2007), ammonium (NH_4) may decrease primary productivity by inhibiting algal growth (Dugdale et al. 2007). Others hypothesize that NH_4 may be shifting primary productivity to *Microcystis*, blue-green algae of less nutritional value (Glibert 2010). On the other hand, clams are believed to capture and largely redirect productivity from the pelagic to the benthic foodweb, not necessarily resulting in a decline in primary productivity overall (Kimmerer 2002). And then again, extensive grazing by clams may deplete populations of phytoplankton to the point where primary productivity is getting reduced. However, the main conclusion drawn by Kimmerer (2002) was that the decrease in the abundance of phyto- and zooplankton was not associated with trends in fish, thus implying that fish declines are not driven by trophic changes.
Dugdale et al. (2007), Glibert (2010), Kimmerer (2002)

Uncertainties

Habitat

Our Picture of Abiotic Habitat Condition Is Limited.
Salinity, water clarity, and temperature are important water quality variables but don't fully define abiotic habitat. Additional information is needed to better define the mechanisms that mediate the effects of water quality variables on aquatic organisms. This also requires a more complete understanding of how the direct effects of water exports interact with the indirect effect of affecting abiotic conditions and the food web. Bennett (2005), Feyrer et al. (2007); Jassby et al. (1995), Kimmerer (2002), Kimmerer et al. (2009), Nobriga et al. (2008), Mac Nally et al. (2010).

Future Habitat Trends Are Uncertain.
There is high uncertainty about future trends in factors that are likely to influence habitat suitability, such as future precipitation, catastrophic natural events, or future policy directions. Bennett (2005), Feyrer et al. (2007), Nobriga et al. (2008).

Causal Relationships Between the Hydrodynamics of the LSZ and the Abundance and Distribution of Young Fishes Remain Largely Unresolved. Jassby et al. (1995), Nobriga et al. (2008).

Data Are Limited on Many Potential Factors Affecting Delta Smelt Habitat Suitability. Many potential factors may affect delta smelt habitat suitability, including food density, entrainment risk, predation risk, or exposure to contaminants. Data on such factors are limited. Interactions between abiotic and biotic habitat components can affect vital rates (per capita birth, death, fecundity) and exert density-dependent effects on population dynamics, although such relationships are currently poorly understood. Bennett (2005), Feyrer et al. (2007), Feyrer et al. (2011), Mac Nally (2010).

Macrophyte Proliferation May Adversely Affect Pelagic Fishes. The invasion of aquatic macrophytes has already substantially changed near-shore fish assemblages and may also have restricted pelagic fish distributions. In particular, the invasive Brazilian waterweed (*Egeria densa*) increases water clarity by trapping suspended sediments, thus negatively affecting native and desirable pelagic fishes. Furthermore, piscivorous yearling striped are typically found in shallower channels that are now subject to increasing density of *Egeria* beds. This may have implications on the result of abundance and possibly changes in available prey items. The association with *Egeria* beds may also skew abundance indices, since fish in shallow water with dense vegetation are les susceptible to being caught in the Fall Midwater Trawl on which these estimates are based. Feyrer et al. (2007), Herbold (pers. comm.), Nobriga et al. (2005, 2008).

Fish Populations

Vertical and Horizontal Distribution Patterns of Zooplankton and Fishes Are Not Fully Understood. There are differences among years and variability among taxa in the tidal movements of zooplankton and fishes in the LSZ that are not fully explained. The migratory behavior of copepods is not consistent with, but also not responsive to, changes in freshwater flow, salinity, or stratification. In the Suisun Bay ship channel, most fishes and zooplankton appeared to undergo tidal vertical migrations, occurring near the surface during flood tides and at depth on ebbs. However, in Suisun Cut some fishes, including delta smelt, appeared to undergo reverse diel migrations, remaining near the surface during the day and at depth during the night. Delta smelt post-larvae in freshwater portions of the Sacramento and San Joaquin rivers were significantly more abundant at depth during the day relative to night, but the results are difficult to interpret without accompanying hydrodynamic information. The mechanisms responsible for variability in migration behaviors remains unclear as are the potential benefits gained by maintaining position in the

LSZ. Bennett et al. (2002), Kimmerer (2002), Kimmerer et al. (2002), Bennett (2005).

Short List of Key Papers on X2 and the Low Salinity Zone since 1995

1995

1. Jassby AD, Kimmerer WJ, Monismith SG, Armor C, Cloern JE, Powell TM, Schubel JR, Vendlinski TJ. 1995. Isohaline position as a habitat indicator for estuarine applications. Ecological Applications 5(1): 272-289.

2001

2. Schoellhamer, DH. 2001. Influence of salinity, bottom topography, and tides on locations of estuarine turbidity maxima in northern San Francisco Bay. Coastal and Estuarine Fine Sediment Processes. Elsevier, Amsterdam, The Netherlands.

2002

3: Kimmerer WJ, Bennett, WA, Burau JR. 2002. Persistence of tidally-oriented vertical migration by zooplankton in a temperate estuary. Estuaries 25: 359-371.

4: Bennett WA, Kimmerer WJ, Burau JR. 2002. Plasticity in vertical migration by native and exotic estuarine fishes in a dynamic low-salinity zone. Limnology and Oceanography 47: 1496-1507.

5: Monismith SG, Kimmerer WJ, Burau JR, Stacey MT. 2002. Structure and flow-induced variability of the subtidal salinity field in northern San Francisco Bay. Journal of Physical Oceanography 32: 3003-3019.

6: Kimmerer WJ. 2002. Effects of freshwater flow on abundance of estuarine organisms: physical effects or trophic linkages? Marine Ecology and Progress Series 243: 39-55.

2004

7: Ruhl CA, Schoellhamer DH. 2004. Spatial and temporal variability of suspended-sediment concentrations in a shallow estuarine environment. San Francisco Estuary and Watershed Science 2(2): 1.

2005

8: Kimmerer WJ. (2005. Long-term changes in apparent uptake of silica in the San Francisco estuary. Limnology and Oceanography 50: 793-798.

9: Bennett WA. 2005. Critical assessment of the delta smelt population in the San Francisco Estuary, California. San Francisco Estuary and Watershed Science 3(2): 1.

2006

10: Hobbs JA, Bennett WA, Burton JE. 2006. Assessing nursery habitat quality for native smelts (*Osmeridae*) in the low-salinity zone of the San Francisco Estuary. Journal of Fish Biology 69: 907-922.

11: Kimmerer WJ. 2006. Response of anchovies dampens effects of the invasive bivalve Corbula amurensis on the San Francisco Estuary foodweb. Marine Ecology Progress Series 324: 207-218.

2007

12: Dugdale RC, Wilkerson FP, Hogue VE, Marchi A. 2007. The role of ammonium and nitrate in spring bloom development in San Francisco Bay. Estuarine, Coastal and Shelf Science 73(1-2): 17-29.

13: Feyrer F, Nobriga ML, Sommer TR. 2007. Multi-decadal trends for three declining fish species: habitat patterns and mechanisms in the San Francisco Estuary, California, USA. Canadian Journal of Fisheries and Aquatic Sciences 64(4): 723-734.

2008

14: Nobriga M, Sommer T, Feyrer F, Fleming K. 2008. Long-term trends in summertime habitat suitability for delta smelt, *Hypomesus transpacificus*. San Francisco Estuary and Watershed Science 6(1): 1.

15: Jassby AD. 2008. Phytoplankton in the Upper San Francisco Estuary: recent biomass trends, their causes and their trophic significance. San Francisco Estuary and Watershed Science 6(1): 2.

2009

16: Kimmerer WJ, Gross ES, MacWilliams ML. 2009. Is the response of estuarine nekton to freshwater flow in the San Francisco Estuary explained by variation in habitat volume? Estuaries and Coasts 32: 375-389.

17: Enright C, Culberson SD. 2009. Salinity trends, variability, and control in the northern reach of the San Francisco Estuary. San Francisco Estuary and Watershed Science, 7(2): 3.

2010

18: Mac Nally R, Thomson JR, Kimmerer WJ, Feyrer F, Newman KB, Sih A, Bennett WA, Brown L, Fleishman E, Culberson SD, Castillo G. 2010. An analysis of pelagic species decline in the upper San Francisco Estuary using multivariate autoregressive modeling. Ecological Applications 20(5): 1417-1430.

19: Thomson JR, Kimmerer WJ, Brown LR, Newman KB, Mac Nally R, Bennett WA, Feyrer F, Fleishman E. 2010. Bayesian change point analysis of abundance trends for pelagic fishes in the upper San Francisco Estuary. Ecological Applications 20(5): 1431-1448.

2011

20: Feyrer F, Newman K, Nobriga M, Sommer T. 2011. Modeling the effects of future outflow on the abiotic habitat of an imperiled estuarine fish. Estuaries and Coasts 34: 120-128.

21: York J, Costas B, McManus G. 2010. Microzooplankton grazing in green water—results from two contrasting estuaries. Estuaries and Coasts 34: 373-385.

22: Winder M, Jassby AD. 2011. Shifts in zooplankton community structure: implications for food web processes in the upper San Francisco Estuary. Estuaries and Coasts 34: 675-690.

23: Schoellhamer DH. 2011. Sudden clearing of estuarine waters upon crossing the threshold from transport to supply regulation of sediment transport as an erodible sediment pool is depleted: San Francisco Bay, 1999. Estuaries and Coasts 34: 885-899

Summaries

1: Isohaline position as a habitat indicator for estuarine populations
Author(s): A. D. Jassby, W. J. Kimmerer, S. G. Monismith, C. Armor, J. E. Cloern, T. M. Powell, J. R. Schubel, and T. J. Vendlinski
Year: 1995
Journal: Ecological Applications
Volume: 5
Number: 1
Pages: 272-289
URL: http://sfbay.wr.usgs.gov/publications/pdf/jassby_1995_isohaline.pdf

Relevance to X2 and LSZ: This paper reports the scientific basis of using X2 (the 2% bottom salinity position) as a habitat indicator to regulate freshwater flow to the Bay Delta Estuary. Participants in EPA's initial estuarine habitat workshop recommended that standards for protecting aquatic life should be based at least in part on the estuary's physical response to fluctuations in freshwater input, i.e., on some "habitat indicator" (sensu Messer 1990, who defines habitat indicator as a "physical attribute measured to characterize conditions necessary to support an organism, population, or community in the absence of pollutants"). The salinity field was of particular interest, and X2 was found to be particularly valuable because by knowing X2 only, one can recreate the entire mean salt field in the Estuary. Additional advantages include that it can be measured with greater accuracy and precision then net freshwater inflow into the estuary. At the same time, statistical analyses demonstrate an unambiguous relationship of X2 with net Delta outflow. The recommendation for X2 as a habitat indicator are based on statistical relationships with year-to-year variability in multiple estuarine resources, including phytoplankton, mollusks, and fish. In the case of fish, clear and pervasive relationships are demonstrated with bottom-foraging fish (starry flounder) and both survival (striped bass) and abundance (longfin smelt and striped bass) of fish that feed in the water column. There is also a clear and pervasive relationship between X2 and phytoplankton-derived particulate organic carbon (POC). The response of the mollusk community is more distinctive. The mollusk abundance index, expressed as the total mollusk density in Grizzly Bay, showed a clear minimum at intermediate values of X2.

2: Influence of salinity, bottom topography, and tides on locations of estuarine turbidity maxima in northern San Francisco Bay
Author(s): D. H. Schoellhamer
Year: 2001
Book: Coastal and Estuarine Fine Sediment Processes
Editor(s): W. H. McAnally and A. J. Mehta
Publisher: Elsevier, Amsterdam, Netherlands
Pages: 373-385
URL: http://sfbay.wr.usgs.gov/sediment/elsevierPDF.html

Relevance to X2 and LSZ: The purpose of this paper is to describe how salinity, bottom topography, and tides influence the locations of the estuarine turbidity maximum (ETM), or suspended sediment concentration (SSC) maxima, in northern San Francisco Bay. ETMs form when salinity is present but they are not associated with a singular salinity. In San Francisco Bay, there is a larger salinity range for ETM location than is observed in other estuaries. The processes that account for a salinity-dependent ETM include gravitational circulation, salinity stratification, and bed storage. The longitudinal salinity gradient, not salinity, creates gravitational circulation and ETMs. All these processes occur in northern San Francisco Bay and are modified by bottom topography and tides. Bottom topography enhances salinity stratification, gravitational circulation, and ETM formation seaward of sills. Salinity stratification in Carquinez Strait, which is seaward of a sill, is greatest during neap tides, which are the only times when tidally averaged SSC in Carquinez Strait was less than that observed landward at Mallard Island. Maximum bottom SSC measured by USGS water quality cruises was located in Carquinez Strait 67 percent of the time, and tidally averaged SSC was greater in Carquinez Strait and the Reserve Fleet Channel, which are both seaward of sills, compared with more landward sites.

3: Persistence of tidally oriented vertical migration by zooplankton in a temperate estuary
Author(s): W. J. Kimmerer, W. A. Bennett, and J. R. Burau
Year: 2002
Journal: Estuaries
Volume: 25
Number: 3
Pages: 359-371
URL: http://www.springerlink.com/content/g55tp2lx7x3r5v66/fulltext.pdf

Relevance to X2 and LSZ: Results from this study show differences among years and variability among taxa in the tidal movements of zooplankton species in the LSZ. The authors demonstrate extensive evidence showing some degree of persistence of various behaviors but were unable to determine how these translate to position maintenance. Based on the presented results, the variable bathymetry in the northern Estuary may play a key role in position maintenance. The migratory behavior of copepods was not consistent and also not responsive to changes in freshwater flow, salinity, or stratification. By contrast, mysids and amphipods responded to freshwater flow regimes. The results for copepods suggest rigid behavior regardless of changing environmental variables, whereas mysids and amphipods altered their behavior depending on local conditions related to freshwater flow. The zooplankton species differed in salinity range. The authors also observed a landward shift of the center of abundance of the copepod *Eurytemora affinis*, which appears to have coincided with the spread of the introduced clam *Potamocorbula amurensis*. They also determined that, since 1988, chlorophyll concentration has been lower in the LSZ compared to the freshwater Delta. During 1988-1998, chlorophyll was generally about 3-fold to 10-

fold lower than previously for salinity values between 0.5 and 20 psu, and a consistent and occasionally steep spatial gradient was observed with higher chlorophyll at salinity values below 1 psu.

4: Plasticity in vertical migration by native and exotic estuarine fishes in a dynamic low-salinity zone
Author(s): W. A. Bennett, W. J. Kimmerer, and J. R. Burau
Year: 2002
Journal: Limnology and Oceanography
Volume: 47
Number: 5
Pages: 1496-1507
URL: http://www.aslo.org/lo/toc/vol_47/issue_5/1496.html

Relevance to X2 and LSZ: This paper examines the degree of flexibility in retention strategies of young fishes in the LSZ during years of highly variable river flow. Young fishes migrated vertically and maintained position in the LSZ, switching between two strategies depending on freshwater flow and longitudinal position of the LSZ. Abundances of four fish species (delta smelt, longfin smelt, striped bass, yellowfin goby) and estimated volume of detrital material were highest at the lower end of the range of salinity sampled in the LSZ. These results support previous observations (see, for example Moyle et al. 1992) showing that an assemblage of young fishes occupies the turbid landward margin of the LSZ. In 1994, striped bass, longfin smelt, and yellowfin goby migrated tidally, occurring near the surface on flood tides and near the bottom on ebb tides. During 1995, this behavior persisted for striped bass and yellowfin goby, even though landward residual currents were present under high river-flow conditions. In contrast, during moderate freshwater flow conditions when the LSZ was positioned in the morphologically complex central Suisun Bay, fishes exhibited reverse diel migrations at the north channel sites such that they were more abundant at the surface by day and at depth by night. The authors suggest that vertical migrations may enhance feeding success, because zooplankton prey similarly migrated in the LSZ.

5: Structure and flow-Induced variability of the subtidal salinity field in northern San Francisco Bay
Author(s): S. G. Monismith, W. J. Kimmerer, J. R. Burau, and M. T. Stacey
Year: 2002
Journal: Journal of Physical Oceanography
Volume: 32
Pages: 3003-3019
URL: http://www-ce.stanford.edu/faculty/monismith/MonismithEtAl2002JPO.pdf

Relevance to X2 and LSZ: This paper provides new insights into the salinity distribution (geographically and over time) of the estuary as it relates to X2. It discusses the structure of the salinity field in northern San Francisco Bay and how it is affected by freshwater flow. Analysis of covariability of Q and X showed a characteristic timescale of adjustment of the salinity field of approximately 2 weeks in response to flow. X2 was found to be proportional to riverflow to the 1/7 power. Thus, the (geographical) length of salinity intrusion into the northern estuary turns out to be relatively insensitive to river flow. The authors argue that the relatively weak dependence of salinity intrusion on flow is owed to dynamic tidal variations, which modulate stratification in the northern estuary. Regardless, they find that X2 can be used as an unambiguous flow-dependent length (as in "distance") scale for salinity intrusion, based on the relationship of $X2 \sim Q^{1/7}$. A key finding from the analysis is a self-similar distribution (whole curve has similar shape as it parts) of depth-averaged salinity in the estuary that is proportional to 1/X2, with a salinity gradient in the center 70% of the region between the Golden Gate and X2. For improving vertically resolved models of salinity intrusion (circulation models), accurately modeling the effects of stratification may be key.

6: Effects of freshwater flow on abundance of estuarine organisms: physical effects or trophic linkages?
Author(s): W. J. Kimmerer
Year: 2002
Journal: Marine Ecology Progress Series
Volume: 243
Pages: 39-55
URL: http://www.waterrights.ca.gov/baydelta/docs/exhibits/DOI-EXH-33I.pdf

Relevance to X2 and LSZ: Kimmerer posits that variations in the abundance or survival of fish in the northern estuary may occur through attributes of physical habitat that vary with flow. Based on reexamining responses of estuarine species to flow and changes in the foodweb (caused by the invasion of *Potamocorbula amurensis*), he concludes variation with freshwater flow of abundance or survival of organisms in higher trophic levels apparently did not occur through upward trophic transfer. All but 3 of the examined species had median salinity between 0.5 and 6, i.e. their distributions overlapped substantially with the LSZ, but large parts of their populations are outside of the LSZ. Fish (with the exception of delta smelt) and shrimp responded positively to flow, whereas chl a (i.e., phytoplankton) and several species of zooplankton had either weak responses to flow or responses that changed after the arrival of *P. amurensis* in 1987. Following the spread of *P. amurensis,* there is a marked decreasing trend in organic matter production and plankton abundance with time, but fish and shrimp did not appear to respond to this change.

7: Spatial and temporal variability of suspended sediment concentrations in a shallow estuarine environment
Author(s): C. A. Ruhl and D. H. Schoellhamer
Year: 2004
Journal: San Francisco Estuary and Watershed Science
Volume: 2

Number: 2
Pages: Article 1
URL: http://escholarship.org/uc/item/1g1756dw#page-1

Relevance to X2 and LSZ: Sediment transport shallow water differs from that in deeper channels because of greater wind wave resuspension, closer proximity to the shore and tributaries, and greater relative benthic filtering. The U.S. Geological Survey measured suspended-sediment concentrations at five locations in Honker Bay, a shallow subembayment of San Francisco Bay, and the adjacent channel to investigate the spatial and temporal differences between deep and shallow estuarine environments. During the first freshwater pulse of the wet season, the channel tended to transport suspended sediments through the system, whereas the shallow area acted as off-channel storage where deposition would likely occur. Following the freshwater pulse, suspended-sediment concentrations were greater in Honker Bay than in the adjacent deep channel, due to the larger supply of erodible sediment on the bed. However, the tidal variability of suspended-sediment concentrations in both Honker Bay and in the adjacent channel was greater after the freshwater pulse than before. During wind events, suspended-sediment concentrations in the channel were not affected; however, wind played a crucial role in the resuspension of sediments in the shallows.

8: Long-term changes in apparent uptake of silica in the San Francisco Estuary
Author(s): W. J. Kimmerer
Year: 2005
Journal: Limnology and Oceanography
Volume: 50
Number: 3
Pages: 793-798
URL: http://www.aslo.org/lo/toc/vol_50/issue_3/0793.html

Relevance to X2 and LSZ: Kimmerer used silica distributions in the northern estuary to infer the apparent uptake of silica and diatom production. Primary production estimated from dissolved silica uptake was similar to production estimated from light and chlorophyll. Production based on dissolved silica (Si_d) averaged 1% and 17% of values prior to the introduction of *P. amurensis*. The Si uptake rates are calculated with a steady-state flux model based on measured salinity gradients and calculated hydraulic residence times. Mixing curves validate the Si-salinity relationship over a range of flow conditions but indicate a slightly negative trend in flow, particularly in June, reflecting the declining hydrograph in the transition from the spring high-flow period to the dry season. However, there is no evidence for an influence of either freshwater flow or temperature, and therefore climate change, on the long-term trend in diatom production.

9: Critical assessment of the delta smelt population in the San Francisco Estuary, California
Author(s): W. A. Bennett
Year: 2005
Journal: San Francisco Estuary and Watershed Science
Volume: 3
Number: 2
Pages: Article 1
URL: http://escholarship.org/uc/item/0725n5vk

Relevance to X2 and LSZ: Delta smelt was formally abundant in the low-salinity and freshwater habitats of the northeastern San Francisco Estuary but is now listed as threatened under the Federal and California State Endangered Species Acts. A key area of controversy centers on impacts to delta smelt associated with exporting large volumes of freshwater from the estuary to supply California's significant agricultural and urban water demands. Uncertainties about the impacts of water export operations on the delta smelt population range from limited knowledge of the numbers of larvae lost in exported water, and impacts of predators near the facilities, to the conditions promoting significant entrainment events at all life stages. Use of a population model suggests that water export operations can impact the abundance of post-larval (about 20 mm fork length) delta smelt, but these effects may not reflect on adult abundance due to other processes, such as impacts of toxic chemicals or changes to the estuarine foodweb by exotic species. Limited work to date has not shown a significant impact of toxic chemicals on delta smelt, however, the author sees a real threat considering the rapidly evolving development and use of new pesticides. Impacts due to exotic species are likely, but there are large uncertainties, in part due to the complexity of interference with delta smelt recruitment. In comparison with other fish, delta smelt has a tiny geographic range being confined to a thin margin of low salinity habitat in the estuary. It is a small and primarily annual species but with low fecundity and a protracted spawning season: key traits that are typically associated with a perennial life history strategy. Delta smelt also do not appear to compensate for their limited reproductive capacity by having precocious offspring; their larvae are pelagic. Overall, the population persists by maximizing growth, survival, and reproductive success on an annual basis despite an array of limiting factors that can occur at specific times and locations. However, population viability analysis using delta smelt abundance estimates for the entire data record (1982–2003) suggest a high probability that the population would decline post 2004.

10: Assessing nursery habitat quality for native smelts (*Osmeridae*) in the low-salinity zone of the San Francisco Estuary
Author(s): J. A. Hobbs, W. A. Bennett, and J. E. Burton
Year: 2006
Journal: Journal of Fish Biology
Volume: 609

Pages: 907-922
URL: ftp://ftp.water.ca.gov/DES/BDCP/Hobbs%20Bennet%20et_al%202006.pdf

Relevance to X2 and LSZ: Delta smelt in the north channel of Suisun Bay exhibited higher densities, larger sizes, increased somatic condition, and greater feeding success, compared to the south channel. Longfin smelt exhibited similar densities, size distributions, and feeding success between both channels, but generally showed poorer somatic condition for the south channel, potentially due to energetic costs associated with documented vertical migration behavior. Overall, the physical conditions of the north channel provided superior habitat for both species, while the south channel afforded only marginal habitat for longfin smelt and very poor habitat for delta smelt. Therefore, the north channel of Suisun Bay acts as critical nursery habitat by providing better feeding and growing conditions.

11: Response of anchovies dampens effects of the invasive bivalve *Corbula amurensis* on the San Francisco Estuary foodweb
Author(s): W. J. Kimmerer
Year: 2006
Journal: Marine Ecology Progress Series
Volume: 324
Pages: 207-218
URL: http://www.int-res.com/articles/meps2006/324/m324p207.pdf

Relevance to X2 and LSZ: When *C. amurensis* invaded the San Francisco Estuary, the distribution of northern anchovy *Engraulis mordax* shifted toward higher salinity, reducing summer abundance by 94% in the low-salinity region of the estuary. The shift in spatial distribution appears to have been a direct behavioral response to reduced food. Bioenergetic calculations showed reduced consumption of zooplankton by all planktivores, including mysids, after *C. amurensis* became abundant, and the anchovy left the low-salinity region of the estuary. This reduced consumption appears to have mitigated effects of the loss of phytoplankton productivity due to increased grazing by the invader, making a greater proportion of the zooplankton productivity available to other fish species.

12: The role of ammonium and nitrate in spring bloom development in San Francisco Bay
Author(s): R. C. Dugdale, F. P. Wilkerson, V. E. Hogue, and A. Marchi
Year: 2007
Journal: Estuarine, Coastal, and Shelf Science
Volume: 73
Pages: 17-29
URL:
http://www.usc.edu/org/seagrant/Publications/PDFs/Dugdale_etal2_007.pdf

Relevance to X2 and LSZ: The authors suggest that San Francisco Bay's substantial inventory of nitrate (NO_3) is unavailable to the resident phytoplankton most of the year due to the presence of ammonium (NH_4) at inhibitory concentrations that prevent NO_3 uptake. Detailed analysis of spring blooms in three embayments over 3 years shows a consistent sequence of events that starts with improved irradiance conditions through stabilization of the water column by stratification or reduced tidal activity. Second, NH_4 concentrations are reduced to a critical range, 1 to 4 μmol per liter, through dilution by precipitation and by phytoplankton uptake. Third, the drawdown of NH_4 enables rapid uptake of NO_3 and subsequent increase in chlorophyll.

13: Multidecadal trends for three declining fish species: habitat patterns and mechanisms in the San Francisco Estuary, California, USA
Author(s): F. Feyrer, M. L. Nobriga, and T. R. Sommer
Year: 2007
Journal: Canadian Journal of Fisheries and Aquatic Sciences
Volume: 64
Pages: 723-734
URL: http://www.water.ca.gov/aes/docs/FeyrerNobrigaSommer2007.pdf

Relevance to X2 and LSZ: General additive model (GAM) predictions for delta smelt, striped bass, and threadfin shad, exhibited significant long-term declines in habitat suitability in the estuary, especially in San Pablo Bay and the South Delta. Simple regression models suggest that water quality may be an important factor in the decline of delta smelt, at least during the past two decades, when food availability was severely reduced by the invasion of *C. amurensis*. The findings corroborate previous hypotheses that the area of suitable physical and chemical habitat has played a role in the decline in fish abundance.

14: Long-term trends in summertime habitat suitability for delta smelt, *Hypomesus transpacificus*
Author(s): M. Nobriga, T. Sommer, F. Feyrer, and K. Fleming
Year: 2008
Journal: San Francisco Estuary and Watershed Science
Volume: 6
Number: 1
Pages: Article 1
URL: http://www.water.ca.gov/aes/docs/NobrigaSummerHabitat.pdf

Relevance to X2 and LSZ: The findings from this study support the hypothesis that basic water quality parameters are predictors of delta smelt relative abundance, but only at regional spatial scales. The authors identified three distinct geographic regions that had similar long-term trends in delta smelt capture probabilities: a primary habitat region centered on the confluence of the Sacramento and San Joaquin rivers and two marginal habitat regions, one centered on Suisun Bay and the other on the San Joaquin River and southern

Sacramento-San Joaquin Delta. Three water quality variables— specific conductance (salinity), Secchi depth (clarity), and temperature—measured concurrently with fish catches all interact to influence delta smelt occurrence (distribution) in the upper San Francisco estuary and are thus indicators of abiotic habitat suitability. Long-term associations of water quality variation and relative abundance were most notable on the perimeter of the species' distribution outside of the Confluence region. Delta smelt relative abundance in the Suisun region varied in association with specific conductance, which is a function of river inflow variation. The San Joaquin region had the warmest water temperatures and the highest water clarity, which increased strongly in this region during 1970–2004. Increasing water clarity, as the authors suggest, is a long-term habitat constriction for delta smelt and a major reason for its absence in the San Joaquin region during summer.

15: Phytoplankton in the upper San Francisco Estuary: recent biomass trends, their causes and their trophic significance
Author(s): A. D. Jassby
Year: 2008
Journal: San Francisco Estuary and Watershed Science
Volume: 6
Number: 1
Pages: Article 2
URL: http://escholarship.org/uc/item/71h077r1

Relevance to X2 and LSZ: The paper examines the effect of flow on phytoplankton biomass in the context of an empirical model that attempts to separate contemporaneous flow conditions from other, perhaps unidentified, forces behind the long-term trend. Regional phytoplankton biomass trends during 1996–2005 are positive in the Delta and neutral in Suisun Bay. The trend in Delta primary productivity is also positive. Changes in phytoplankton biomass and production during the last decade are therefore unlikely to be the cause of more recent metazoan declines. Freshwater flow variability and its effect on particle residence time are the main source of interannual phytoplankton variability in the Delta, including the upward trend. This conclusion is supported by trend analyses; the concurrence of these time trends at widely-separated stations; empirical models at the annual and monthly time scales; particle residence time estimates; and experience from other estuaries. The reason behind Suisun Bay phytoplankton's low responsiveness to flow variability appears to be *C. amurensis*, which has maintained the phytoplankton community mostly at low levels by vigorous filter-feeding. In the past, flows into Suisun Bay generally diluted the higher phytoplankton concentrations within the bay; now they bring in higher phytoplankton concentrations from upstream. Accordingly, Jassby suggests loading of phytoplankton and phytoplankton-derived detritus accounts for much of the phytoplankton carbon supply to Suisun Bay. In the Delta, *Corbicula fluminea* may be conceivably responsible for a significant part of the observed interannual variability in phytoplankton biomass. Macronutrient supply, on the basis of dissolved nutrient levels, does not seem to be important as a determinant of phytoplankton variability. Water temperature increased significantly during 1996–2005. The temperature increase is significant and, at least partially independent of flow changes, but its net effect on the phytoplankton community is unknown because of differential effects on growth and loss processes.

16: Is the response of estuarine nekton to freshwater flow in the San Francisco Estuary explained by variation in habitat volume?
Author(s): W. J. Kimmerer, E. S. Gross, and M. L. MacWilliams
Year: 2009
Journal: Estuaries and Coasts
Volume: 32
Pages: 375-389
URL: http://www.springerlink.com/content/26pr3h5574605083/fulltext.pdf

Relevance to X2 and LSZ: The key finding in this study is that of eight species, only two (American shad and striped bass) had habitat relationships to X2 that appeared consistent with their relationships of abundance (or survival) to X2. The authors conclude that mechanisms other than variation in physical habitat must underlie responses of abundance to flow for most species. The authors calculated an index of total habitat for each species by combining resource selection functions for salinity and depth with estimates of habitat volume at five different flows using the TRIM3D hydrodynamic model. The resource selection functions for the examined species were consistent for data from different sampling programs with the exception of longfin smelt, which had a peak resource value at salinity near 20 in the Bay Study otter trawl (sampling in deeper water, more seaward) but near 10 or less in the other samples (sampling in shallower water, more landward).

17: Salinity trends, variability, and control in the northern reach of the San Francisco Estuary
Author(s): C. Enright and S. D. Culberson
Year: 2009
Journal: San Francisco Estuary and Watershed Science
Volume: 7
Number: 2
Pages: Article 3
URL: http://escholarship.org/uc/search?entity=jmie_sfews;volume=7;issue=2

Relevance to X2 and LSZ: The key conclusion here is that climate is the primary long-term salinity *variability* driver at the seasonal and annual scale. The water projects influence the trend of the annual and some monthly means in outflow and salinity, but exert far less influence on variability. Notably, both outflow and salinity are generally more variable in the water project era concordant with watershed precipitation. However, the water projects have decoupled long-term trends in annual mean outflow and salinity from long-term trends in climate forcing. Outflow trends downward in opposition to the precipitation trend in the post-project period. The authors also note an apparent reduction in fall outflow from the Delta and salinity variability in the northern reach in the last decade as the water projects have operated more closely to maximum export-inflow ratios.

18: An analysis of pelagic species decline in the upper San Francisco Estuary using multivariate autoregressive modeling (MAR)
Author(s): R. Mac Nally, J. R. Thomson, W. J. Kimmerer, F. Feyrer, K. B. Newman, A. Sih, W. A. Bennett, L. Brown, E. Fleishman, S. D. Culberson, and G. Castillo
Year: 2010
Journal: Ecological Applications
Volume: 20
Number: 5
Pages: 1417-1430
URL:
http://online.sfsu.edu/~modelds/Files/References/MacNallyetal2010EcoApps.pdf

Relevance to X2 and LSZ: The authors applied a Bayesian (probabilistic) analysis framework to validate fifty-four relationships representing the state of knowledge of how abiotic habitat factors directly relate to declining fish abundance in the upper San Francisco Estuary and indirectly to these fish populations through the food web. An underlying expert model specified whether particular trophic or covariate effects might be influential. X2 and increased water clarity over the period of analyses were two factors affecting multiple declining taxa (including fishes and their main zooplankton prey). There was a pervasive relationship of spring X2 with abundances of longfin smelt. There is evidence of potential effects of water exports on delta smelt and threadfin shad. Increases in water exports in both winter and spring were negatively associated with abundance of delta smelt and increases in spring exports with abundance of threadfin shad. The results for delta smelt were consistent with multiple effects of temperature, feeding, exports, and introduced species. The results for striped bass are consistent with effects of feeding and water clarity. Covariates (factors thought to be important for one or more of the response variable) explained 51% variation, suggesting that some aspects of the environment that can be managed are associated with the declining fish species (e.g., X2 and exports). Other potential remedial actions would be difficult or impossible to enact (e.g., total removal of *C. amurensis*).

19: Bayesian change-point analysis of abundance trends for pelagic fishes in the upper San Francisco Estuary
Author(s): J. R. Thomson, W. J. Kimmerer, L. R. Brown, K. B. Newman, R. Mac Nally, W. A. Bennett, F. Feyrer, and E. Fleishman
Year: 2010
Journal: Ecological Applications

Volume: 20
Number: 5
Pages: 1431-1448

Relevance to X2 and LSZ: By using multispecies change point models, the authors find strong evidence for a common change point for all POD species in 2002. Abiotic variables, including water clarity, position of X2, and the volume of freshwater exported from the estuary, explained some variation in species' abundances over the time series, but no selected covariates could explain statistically the post-2000 change points for any species. Species-specific, covariate-conditioned change point models indicated step declines in abundances (i.e., abrupt declines that could not be modeled by the included covariates) of delta smelt and longfin smelt in 2004 and of striped bass and threadfin shad in 2002. In a variable-selection model for delta smelt, water clarity and winter exports both had high probability of inclusion and a negative effect. In the variable-selection model for longfin smelt, water clarity and spring X2 had high probability of inclusion. In the variable-selection model for striped bass, water clarity and the autocorrelation term had high probability of inclusion. No variables had high probability of inclusion in the threadfin shad variable selection model. The authors used a hierarchical Bayesian modeling framework, which allows sampling or measurement error to be separated from actual variation in underlying abundances, while fitting a wide variety of process models.

20: Modeling the effects of future outflow on the abiotic habitat of an imperiled estuarine fish
Author(s): F. Feyrer, K. Newman, M. Nobriga, and T. Sommer
Year: 2011
Journal: Estuaries and Coasts
Volume: 34
Pages: 120-128

Relevance to X2 and LSZ: The authors report a 78% decrease in an annual abiotic habitat index for delta smelt over the study period (1967 – 2004). Using the General Additive Model developed by Feyrer et al. (2007), only specific conductance and Secchi depth accounted for a meaningful reduction of null deviance (i.e., unexplained variability). The final model with specific conductance and Secchi depth accounted for 26% of the deviance. The CALSIM II model was used to simulate future X2 scenarios under seven different development (each assuming a constant level of development) and climate change scenarios, representing a range of drier and wetter possibilities. Modeled future conditions produced smaller values of the delta smelt habitat index relative to the modeled present day condition, the only exception being in critical years when all values were similar and low. These modeling results suggest further declines in habitat across all water year types. The authors conclude that recovery targets for delta smelt will be difficult to attain if the modeled habitat conditions are realized. A key part of the concern for delta smelt is that the lowest levels of suitable habitat coincide with the habitat being located further upstream in closer proximity to anthropogenic sources of mortality such as water diversions and certain contaminant sources. Locations of X2 downstream of the confluence of the Sacramento and San Joaquin rivers results in a dramatic increase in the habitat index, when the LSZ encompasses the expansive Suisun and Grizzly Bays, a larger area of suitable habitat.

21: Microzooplankton grazing in green water—results from two contrasting estuaries
Author(s): J. York, B. Costas, and G. McManus
Year: 2011
Journal: Estuaries and Coasts
Volume: 34
Pages: 373-385
URL:
http://online.sfsu.edu/~modelds/Files/References/YorkEtAl2010EstuariesCoasts.pdf

Relevance to X2 and LSZ: Using the dilution method to measure seasonal variations in microzooplankton grazing on phytoplankton, the authors found many instances of saturated as well as insignificant grazing in San Francisco Bay. They suggest that saturation in some cases may result from high particle loads and that insignificant grazing may result from extreme saturation of the grazing response due to the need to process non-food particles. There was no evidence of nutrient limitation for phytoplankton growth. In a series of two-point dilutions run in spring and summer 2007, the authors found increasing phytoplankton growth rates and microzooplankton grazing rates with increasing salinity. Grazing rates in San Francisco Bay and Long Island Sound were similar to those found in other estuaries.

22: Shifts in zooplankton community structure: implications for food web processes in the upper San Francisco Estuary
Author(s): M. Winder and A. D. Jassby
Year: 2011
Journal: Estuaries and Coasts
Volume: 34
Pages: 675-690
URL: http://www.springerlink.com/content/b30544u2xx0l235u/fulltext.pdf

Relevance to X2 and LSZ: This paper documents major changes in the zooplankton species composition in Suisun Bay and the Delta between 1972 and 2008, largely associated with direct and indirect effects of introductions of non-native bivalve and zooplankton species. Previously dominant copepod species were essentially replaced by newly introduced species over the 37-year study period. Major changes occurred also within the mysid community, with a strong decline in biomass by the end of the 1980s and species composition changes in the early 1990s. In Suisun Bay, the historically abundant calanoid copepods and rotifers have declined significantly, but their biomass has been compensated to some extent by the introduced cyclopoid *Limnoithona tetraspina*. The increasing dominance of *L. tetraspina* in the early 1990s in Suisun Bay coincided with declining trends in the average micro- and mesozooplankton size in this region. The Delta has also experienced long-term declining biomass trends, particularly of cladocerans and rotifers, although calanoid copepods have increased since the early 1990s due to the introduced *Pseudodiaptomus spp*. However, zooplankton biomass in the Delta has remained at a low level since the mid-1980s. Changes in the biomass, size, and possibly chemical composition of the zooplankton community imply major alterations in pelagic food web processes, including a drop in prey quantity and quality for foraging fish and an increase in the importance of the microbial food web for higher trophic levels.

23: Sudden clearing of estuarine waters upon crossing the threshold from transport to supply regulation of sediment transport as an erodible sediment pool is depleted: San Francisco Bay, 1999
Author(s): D. H. Schoellhamer
Year: 2011
Journal: Estuaries and Coasts
Volume: 34
Pages: 885-899
URL: http://bayplanningcoalition.org/wp-content/uploads/Schoellhamer-2001-sudden-clearing.pdf

Relevance to X2 and LSZ:

The paper presents a quantitative conceptual model of an estuary with an erodible sediment pool and transport or supply regulation of sediment transport. The author offers a hypothesis that the Bay contained an erodible pool of sediment that was depleted in the late 1990s. The hypothesis is supported by an analysis of historical changes in bed sediment volume. The study was motivated by a statistically significant 36% step decrease in SSC in San Francisco Bay from water years 1991–1998 to 1999–2007. This step change in the water year mean SSCs from WY 1998 to 1999 was significant (one-sided rank-sum test $p<0.01$) at all sites except San Mateo Bridge. At the interannual time scale of this study, an erodible sediment pool is the difference between the existing sediment mass and the sediment mass of the estuary at equilibrium (no net deposition or erosion). An erodible sediment pool is depleted when transport-regulated suspension becomes supply-regulated. When regulation of suspended sediment crosses the threshold from transport regulation to supply regulation, suspended mass can rapidly decrease. At the interannual time scale, the erodible sediment pool is larger than at the tidal time scale. Changes in the erodible sediment pool caused by changes in hydrodynamic forcing, specifically decreased tidal prism due to construction fill and levees, are assumed to be negligible. Application of the quantitative conceptual model to San Francisco Bay demonstrates that depletion of an erodible sediment pool in 1999 would cause a sudden decrease in SSC. Supply of hydraulic mining sediment increased bed sediment volume by at least 260 Mm^3 in the late 1800s, almost entirely in Suisun and San Pablo Bay. From the early to mid-1900s, there was a second pulse of sediment about 60% of the hydraulic mining sediment pulse and conceivably caused by urbanization or increased agricultural land use. Without an erodible sediment pool, annual suspended mass would be dependent on river supply and would not suddenly decrease, unless the river supply suddenly decreased. The river supply to San Francisco Bay varies annually and decreased 1.3%/year during the later half of the twentieth century (Hestir et al. submitted). The decreasing watershed sediment supply contributes to decreased SSC but cannot account for the step decrease in SSC. According to the author, changes in the San Francisco Bay ecosystem in the 2000s have been symptomatic of the sudden clearing.